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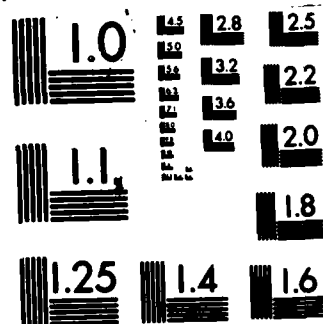
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CURRENT RESEARCH AT THE U.S. NAVAL BIODYNAMICS LABORATORY  
ON HUMAN WHOLE-BODY MOTION AND VIBRATION

John C. Guignard, Alvah C. Bittner, Jr., and Mary M. Harbeson



July 1983

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20. Abstract (Continued)

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## SUMMARY PAGE

### PROBLEM

This report provides an overview of recent, ongoing, and planned whole-body motion and vibration research at the Naval Biodynamics Laboratory. Three interrelated efforts are reviewed: (1) Performance Evaluation Tests for Environmental Research; (2) the development of experimental paradigms and statistical methodologies; and (3) identification of vibration effects on performance. Three studies in which performance tasks were administered under various levels of vibration are summarized.

### FINDINGS

A program to assess human whole-body vibration effects is under way at the Naval Biodynamics Laboratory (NBDL). This program, together with affiliated ship-motion and impact-acceleration programs, is directed at establishing correlations between psychological, physiological, and biodynamic (inertial) responses of human volunteer subjects. Mechanical input forces of interest across programs are the kind experienced in ship and aircraft crewstations. Recent research has been directed at the development of experimental paradigms, statistical methodologies, and strategic plans for systematic explorations of pertinent parameters of the motion environment.

### RECOMMENDATIONS

Results of the vibration program suggest: using repeated measures methodologies; (2) experimental focus on mechanical interference with input (e.g., visual) and output (e.g., motor) processes; and (3) study of the nature of performance changes during repeated and longer-term exposures. Ongoing and future research efforts are aimed at these recommendations.

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This paper was presented at the Meeting of the United Kingdom Informal Group on Human Response to Vibration in London, England, September 1982.

Trade names of materials or products of commercial or non-government organizations are cited where essential for precision in describing research procedures or evaluation of results. Their use does not constitute official endorsement or approval of the use of such commercial hardware or software.

The volunteers used in this study were recruited, evaluated and employed in accordance with the procedures specified in the Secretary of the Navy Instruction 3900.39 series and the Bureau of Medicine and Surgery Instruction 3900.6 series. These instructions are based upon voluntary consent, and meet or exceed the prevailing national and international guidelines.

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ABSTRACT

This report provides an overview of recent, ongoing, and planned whole-body motion and vibration research at the Naval Biodynamics Laboratory. Three interrelated efforts are reviewed: (1) Performance Evaluation Tests for Environmental Research; (2) the development of experimental paradigms and statistical methodologies; and (3) identification of vibration effects on performance. Three studies in which performance tasks were administered under various levels of vibration are summarized. Results of the vibration program suggest: using repeated measures methodologies; (2) experimental focus on mechanical interference with input (e.g., visual) and output (e.g., motor) processes; and (3) study of the nature of performance changes during repeated and longer-term exposures. Ongoing and future research are aimed at these recommendations.

INTRODUCTION

Background

A program to assess human whole-body vibration effects is under way at the Naval Biodynamics Laboratory (NBDL). This program, together with affiliated ship-motion and impact-acceleration programs, is directed at establishing correlations between psychological, physiological, and biodynamic (inertial) responses of human volunteer subjects. Mechanical input forces of interest across programs are the kind experienced in ship and aircraft crewstations. Recent research has been directed at the development of experimental paradigms, statistical methodologies, and strategic plans for systematic explorations of pertinent parameters of the motion environment. In late 1981, NBDL hosted the International Workshop on Research Methods in Human Motion and Vibration Studies. This workshop and cognate analytic investigations have provided a framework for our present efforts. A continuing series of experimental studies is aimed both at defining methodology for long term investigations and elucidating the magnitude and character of vibration effects upon task performance. These studies have utilized tasks drawn from an associated NBDL program to identify experimental tasks characterized by reliability, ease of statistical analysis, sensitivity to vibration effects, and overall suitability for repeated-measures testing.

Purpose

The purpose of this report is to provide an overview of recent, ongoing and planned research at NBDL related to whole-body motion and vibration effects with particular reference to human performance.



## RESEARCH OVERVIEW

Three interrelated efforts will be reviewed in this section: (1) Performance Evaluation Tests for Environmental Research; (2) experimental paradigms and statistical methodologies; and (3) identification of vibration effects on performance.

### Performance Evaluation Tests

An engineering approach to the development and standardization of a battery of Performance Evaluation Tests for Environmental Research (PETER) has been followed over the last five years at the Naval Biodynamics Laboratory (NBDL). This approach has involved test and evaluation of performance tasks prior to their being employed in the assessment of environmental effects. The goal of this effort has been to ensure that selected tasks will be suitable for simple analysis and interpretation when employed in repeated measures experiments (Kennedy & Bittner, 1977; Bittner & Carter, 1981). The emphasis is on statistical requirements for repeated measures experimental designs because environmental research usually includes measurement of performance before, during, and after exposure to an unusual environment.

The criteria for suitable stability of tests used in repeated measures experiments have been delineated by Jones (1972); Jones, Kennedy and Bittner (1981); and Bittner and Carter (1981). These authors have suggested that "stability" exists when: (a) group mean performance in a standard environment has reached an asymptote or evidences a slight constant slope (b) day-to-day between-subject variance is constant and (c) relative performance standings among subjects, as indicated by intertrial correlations, are constant for all pairs of days. The importance of task stability has not been fully recognized in the development of previous batteries. Without mean stability, changes of the means during a repeated-measures experiment are not interpretable (Campbell & Stanley, 1963). In addition, variance stability and differential stability ensure that the assumptions of repeated measures analysis of variance are met (Winer, 1971), and further, they verify the temporal generalizability of subjects' scores (Cronbach, Gleser, Nanda, & Rajarantnam, 1972). Lastly, differential stability ensures that "what is being measured" does not change over time (Alvares & Hulin, 1972; Bittner, 1979; Jones, Kennedy & Bittner, 1981). "Stability" is the essential quality required for statistically and scientifically meaningful repeated measures experiments.

Over five dozen tasks have been evaluated since battery development was begun. Reports of these evaluations have been published as parts of collections, proceedings, and journals<sup>1</sup>. Of the tasks evaluated, about 30 percent have been found suitable for repeated measures applications. Another 20 percent have been found acceptable for limited use, and the remaining 50 percent could not be recommended. Pertinently, several of the

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<sup>1</sup> Appendix A contains a selected bibliography of NBDL human performance publications.

one position off and implies that reading errors are failures to ac-

unsuitable tasks previously had been employed in vibration and other biodynamic research. For example, the Landolt C Reading Test was found to suffer from substantial deficiencies (Guignard, Rittner, Einbender & Kennedy, 1980). Figure 1 shows the location of error responses relative to target position; it indicates that most error responses (96%) were only one position off and implies that reading errors are failures to accurately specify the location of breaks, not failures of break detection. This deficiency and a lack of differential stabilization, contraindicate the use of this task for environmental research. The unsuitability of the majority of tasks brings into question the validity of much of the literature concerning environmental effects on human performance.

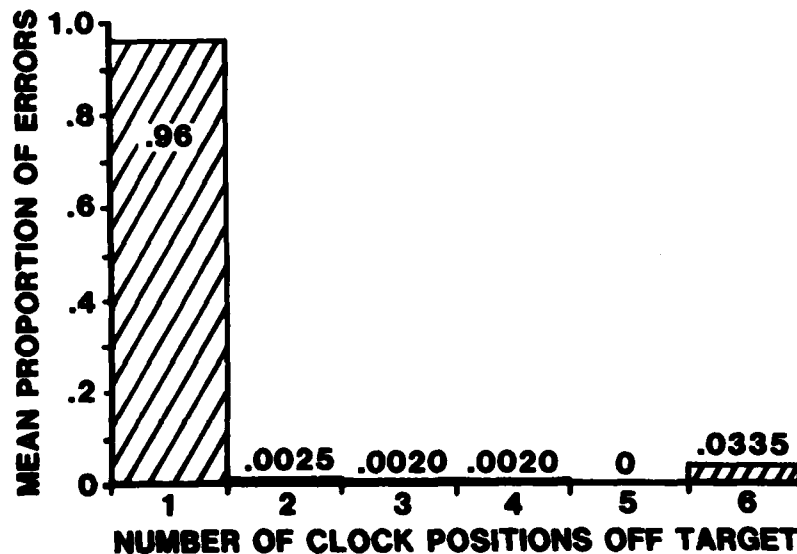


Figure 1. Mean Proportion of Clock Position Errors Over Days.

#### Paradigms and Statistical Methodologies

Development of statistical methodologies and experimental paradigms applicable to biodynamic and other environmental research has been of continuing interest over the last five years. Initial efforts were concerned with both collection and development of tools applicable to the evaluation of the statistical suitability of performance tasks in support of the program described above. Early reports of these methodological efforts have been recently collected (Bittner, Jones, Carter, et al., 1981) and synoptically integrated (Bittner & Carter, 1981). Related statistical developments have been published since these earlier reports were completed. These include several evaluations of the use of "averaged correlations" for estimation of reliabilities and cross-correlations (Bittner, 1982; Bittner, Dunlap & Jones, 1982; Dunlap, Jones & Bittner, 1983). These evaluations have supported the use of averaged correlations, over correlations of averages, as offering a viable differential technique for studies with limited subject resources ( $N < 10$ ). In addition, efforts have included reports questioning the efficacy of proportion-of-baseline and slope metrics (Bittner, 1981; Carter & Krause, 1983). The problems of proportion of baseline and slope metrics it is noteworthy, parallel those

accompanying the use of difference scores (Cronbach & Furby, 1970 ), these other derived scores must be considered suspect. Altogether these methodological developments can be applied in the evaluation of tasks and other measures prior to their use in repeated measures research.

Current methodological efforts are primarily concerned with the issues of assessing vibration and related environmental effects. Embedded in the vibration research program, to be described in the following section, are attempts to delineate and overview the various issues experimentally. In addition to this direct approach, our laboratory late last year sponsored the International Workshop on Research Methods in Human Motion and Vibration Studies. This workshop brought together some 80 investigators engaged in biodynamic research to discuss methodologies of measurement (Guignard & Harbeson, in preparation)<sup>2</sup>

### Investigations of Vibration Effects on Performance

Three investigations of the performance effects of whole-body vibration have been conducted over the last two years. These investigations all drew from the same subject population and employed the same vibration machine.

Subjects. The subjects were Navy enlisted men (aged 18 to 24) who had volunteered for duty as biodynamic research subjects. They had been selected to be unusually free of skeletal, cardiopulmonary and other medical or psychological conditions which would preclude participation in potentially hazardous environmental research. The subjects were otherwise typical of the general enlisted population. All subjects were recruited, evaluated, and employed in accordance with SECNAV Instruction Series 3900.39 and BUMED Instruction Series 3900.6, which are standing regulations of the US Navy. These instructions are based upon informed voluntary consent and meet the provisions of prevailing national and international guidelines regarding proper human experimentation. A more detailed description of the volunteers and their selection is given by Thomas, Majewski, Ewing, and Gilbert (1978).

Apparatus. The subjects were seated on the NBDL 28,000 lbf electrodynamic vibration machine, operating in its vertical mode (i.e., vibrating in the direction of gravity), and equipped with a rigid seat and foot-rest directly coupled to the armature of the machine. The hard seat was, for comfort, shaped in a fashion similar to that of a farm tractor seat, and incorporated the seat reference accelerometer used to monitor the vibration input to the subject in his Z-axis. Only gravity was used for restraint: there were no straps or back-rest. The machine is capable of shaking a seat and human subject without extraneous mechanical support or appreciable distortion of the vibration waveform in the conditions studied: rms acceleration at the seat was controllable to within  $\pm 1\%$ ; vibration frequency was controllable to within  $\pm 0.5\%$ ; and total harmonic distortion was negligible.

Purpose of the Investigations. The general purpose of the investigations has been to: (1) provide a reliable methodological basis for systematic testing over an extensive range of frequencies, amplitudes, and durations; and (2) to delineate the human performance capabilities upon which to focus. The investigations are summarized in turn below.

Guignard, Bittner, and Carter (1982)

Twenty volunteer subjects, divided into three groups, were rehearsed and then tested before (B), during (D), and after (A) whole-body vibration. Group 1 included 7 experienced subjects who were available only for the first phase of the study before being transferred. Group 2 was made up of 6 experienced subjects, and the third group consisted of six new (inexperienced) subjects. Data from the seventh new volunteer, who was identified as a visually atypical subject (VAS), was treated separately. Vibration conditions are shown in Table 1.

Table 1 Vibration Conditions

Experiment	Subject Groups	N	Frequency (Hz)	Acceleration (g <sub>z</sub> rms)
1	G1 & G2	13	8	0.21
2	G2	6	16	0.43
3	G2	6	32	0.85
4	G2 & G3 + VAS	14	8	0.21

Three paper-and-pencil tasks involving visual, motor, and cognitive skills were used. The tasks were: "Spoke", a speed of tapping task (Bittner, Lundy, Harbeson, & Kennedy, 1982). "Aiming", a test of fine motor coordination (Fleishman & Ellison (1962)), and "Coding" a test involving mental computation (Pepper, Kennedy, Bittner, & Wiker, 1980). Means and standard deviations for Coding, Spoke, and Aiming are shown in Tables 2, 3, and 4 respectively.

No significant overall differences were found among the three groups before, during, or after vibration at the 8 Hz condition. However, the inexperienced subjects showed a decrement in Coding after vibration. Individual differences were a large source of variation for all tasks under all conditions, recommending repeated measures methodology. There was an overall improvement in Spoke and Aiming but not Coding. Fine structure analysis indicated that simple additive models were adequate for describing the effects of vibration, at least at 8 Hz with subjects with normal vision (the use of proportional and/or complex models was not supported by the data).

2 Papers to be published in the proceedings of the workshop are listed in Appendix B.

Multiple correlation analysis was performed on the Coding results to estimate the magnitude of vibration effects on a mental task. Very little, if any, change in scores during vibration could be attributed to mental rather than to mechanical visual and manual effects. These results suggested experimental focus on the etiology of effects in future studies.

Table 2 Means (and Standard Deviations) for Coding

Experiment	Frequency	Before	During	After
1	8 Hz	73(12)	60(14)	78(11)
2	16 Hz	72(11)	75( 7)	76(11)
3	32 Hz	80(11)	79(26)	75( 8)
4	8 Hz	84(10)	70(10)	80( 7)

Table 3 Means (and Standard Deviations) for the Spoke Test

Experiment	Frequency	Before	During	After
1	8 Hz	10.1(1.3)	10.3( .8)	9.5(1.1)
2	16 Hz	8.7(1.0)	9.0(1.1)	8.9(1.0)
3	32 Hz	8.3( .8)	8.8(1.0)	8.3(1.2)
4	8 Hz	8.2( .9)	8.9(1.2)	7.9(1.2)

Table 4 Means (and Standard Deviations) for the Aiming Test

Experiment	Frequency	Before	During	After
1	8 Hz	415(28)	379(44)	438(30)
2	16 Hz	453(43)	456(21)	469(41)
3	32 Hz	482(36)	472(28)	466(59)
4	8 Hz	495(59)	438(15)	523(60)

The reliability of applying current vibration standards to performance was questioned in this study. While Spoke and Coding performance were found equivalent across vibration conditions, Aiming was found to be differentially affected at 8 Hz vs 16 and 32 Hz. Indeed, the vibration decrement is an order of magnitude greater at the lowest frequency, indicating mechanical interference.

The results showed that performance of the Coding and Spoke tasks (although not Aiming) was significantly degraded in a way consistent with the human response frequency function for task performance embodied in the international standard (ISO 2631-1978) "Fatigue/Decreased Proficiency Boundary". In other words, the data appear to only partially support the frequency-weighting given in the standard to provide an "iso-decrement" guideline, at least for the relatively high acceleration levels and short durations used in our experiment. It is noteworthy that previously, Guignard, Landrum and Reardon (1976) found no significant change in performance scores on a variety of tests during human exposure to the corresponding vibration levels standardized by ISO 2631-1978 for long-term exposures up to 8 hours, they concluded that, for such exposures at least, the standard might be unduly conservative. Altogether the present and previous research indicate that the guidelines in ISO 2631-1978 are indeed based uncertainly on extrapolation from very meager data and may require revision.

Bittner, Guignard, Woldstad, & Carter (1982)

Three trials of Coding were administered each before, during, and after whole-body sinusoidal vibration. Four inexperienced and two experienced subjects were tested at 8 Hz / 0.21 g<sub>z</sub> rms. Results indicated that individual differences and related (group) interactions accounted for respectively 51.1% and 5.0% of the total sum-of-squares. Simple vibration effects accounted for 14.8% of the variance.

Figures 2 and 3 illustrate the nature of the group interactions. Figure 2 shows that, while the inexperienced subjects (Group 1) showed improved performance subsequent to vibration, experienced subjects (Group 2) showed a decline. This finding appears, at first glance, to be in conflict with the report of Guignard et al. (1982) who found that their inexperienced group showed a decline (Before-After) while their experienced group demonstrated improvement. However, reexamination of Table 2 reveals increases early in practice between measures Before and After (e.g., Exp. 1), but declines in later experiments (Exp. 4). From current and previous findings, a number of complex interactions of experience and practice might be posited; however, additional empirical evidence appears preferable to speculative attempts at explanation using the current data base. Figure 3 shows that both groups' performance improved under vibration with practice; however, inexperienced subjects were slower to improve. Interestingly Guignard et al. (1982) were unable to demonstrate improvements under vibration directly, as they had only single trials under each condition. However, comparison of their Experiments 1 and 4 (8Hz / 0.21 g<sub>z</sub> rms) reveals an apparent reduction of the overall Baseline-Vibration difference from 15.5 to 12.0 for repeated testings with several months separation. Thus, the results of Guignard et al. (1982) are not inconsistent with those of the present experiment and indicate task

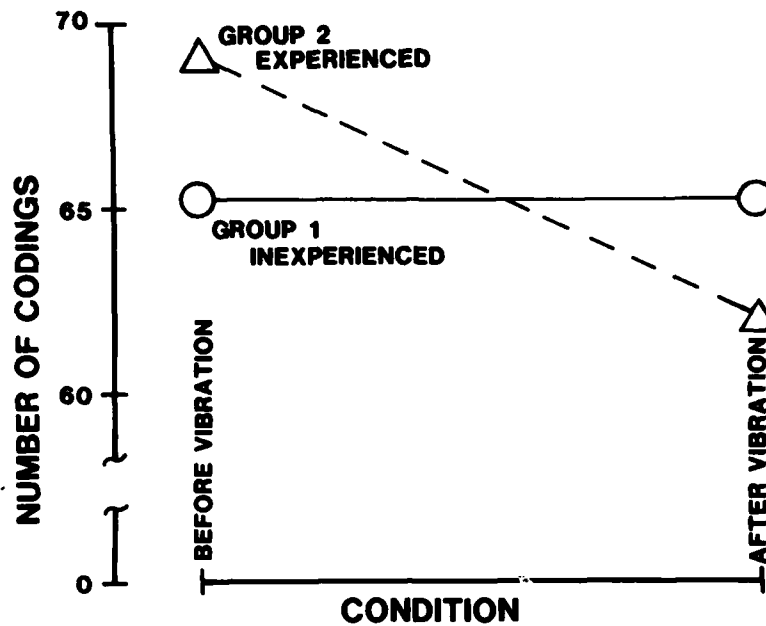


Figure 2. Group Scores Before and After Vibration.

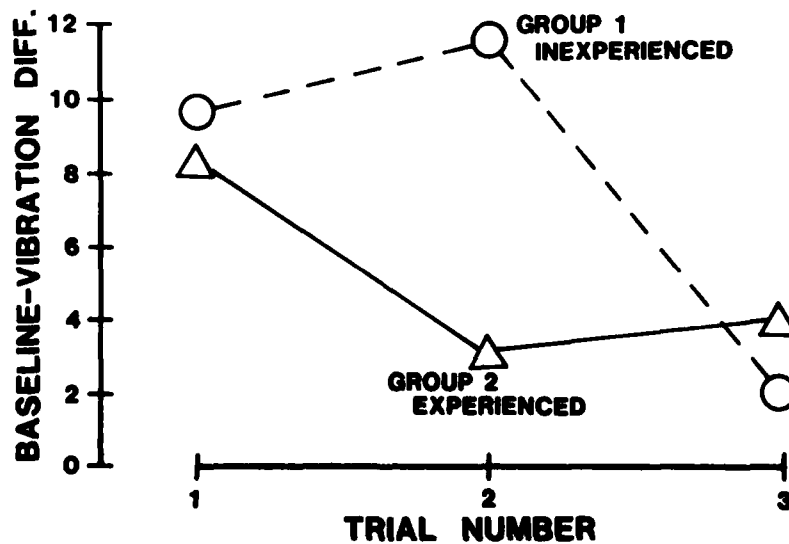


Figure 3. Group Baseline-Vibration Differences Over Trials.

learning under vibration. The present and previous results indicate reduction in vibration performance decrements with practice and an interaction of experience and practice with performance after vibration. Altogether, the reduction in decrement with practice under vibration recommends reconsideration of ISO 2631-1978 limits when subjects are experienced. Present performance limits were largely derived during brief exposures where practice was meager.

Supplementing performance measurements, direct scaling (Stevens, 1975), was used to evaluate subjective estimates of capacities for "Seeing", "Thinking", and "Writing". Thinking was seen to have the greatest remaining capacity, Seeing a lesser capacity, and Writing the least remaining capacity. Significantly, 5 of 6 subjects also specified Writing as their greatest problem prior to estimation instructions ( $p < .02$ ). Direct scaling, supporting the Guignard et al (1982) performance results, indicated that vibration effects were largely input-output in nature (Seeing-Writing) with the greatest problem being output (Writing).

It was concluded that future research should utilize control groups, and repeated measures methodologies. With regard to ISO 2631-1978, it was recommended that future research be directed at the under-explored realm of long-term psychological, physiological, and bio-mechanical changes.

#### Woldstad, Bittner, and Guignard (1982)

An auditory-input/keypad-output system was evaluated for use as a performance test system that would be independent of artifactual vibrational decrement. Six young Navy volunteers were administered a non-cognitive Auditory Response Task before, during, and after whole-body sinusoidal vibration. The task consisted of the subject receiving a number through a computer verbal input system, and then responding by pressing the key corresponding to that number on the computer mini-pad. Six subjects were tested, two each, at three vibration conditions (8 Hz/0.21 g<sub>z</sub>rms, 16 Hz/0.43 g<sub>z</sub>rms, and 32 Hz/0.85 g<sub>z</sub>rms).

A repeated measures analysis of variance (ANOVA) was conducted on the scores from the Auditory Response Task. Results showed no direct decrement due to vibration, but a moderately significant subjects-within-conditions by frequency interaction. Practice effects were evident with an increase in performance in the After condition, in comparison to the Before condition, over all frequencies; however learning was substantially greater at 8 Hz than at 16 or 32 Hz as seen in Figure 4 (see Figure 1). The most difficult condition elicited greatest learning.

There were significant differential individual responses to vibration ( $(D-(B+A))/2$ ) under the different frequency conditions. Figure 5 illustrates the source of this effect. At 8 Hz it is clear that the range of decrement was larger than at 16 or 32 Hz. It is believed that this was observed because one of the subjects at 8 Hz developed the ability to grasp the keypad and maintain a fixed hand relationship. This subject not only showed no decrement in performance due to vibration, but actually performed better under it.



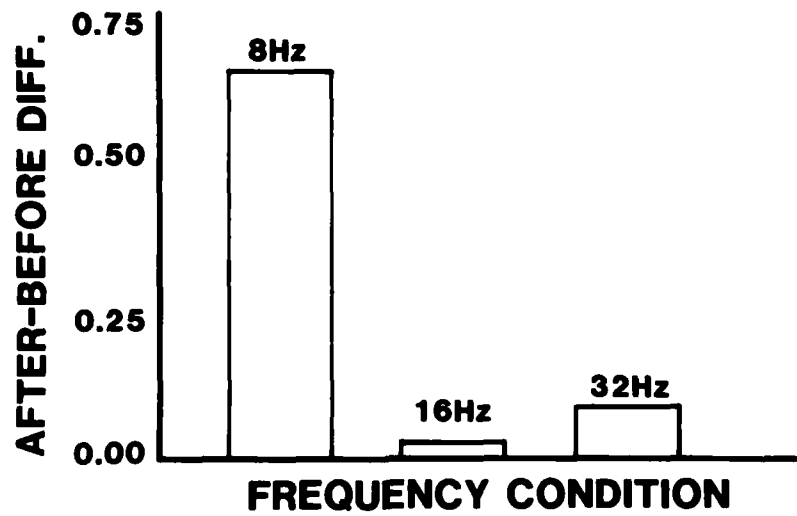


Figure 4. Auditory Response Transcription Differences (After-Before) at Three Frequency Conditions.

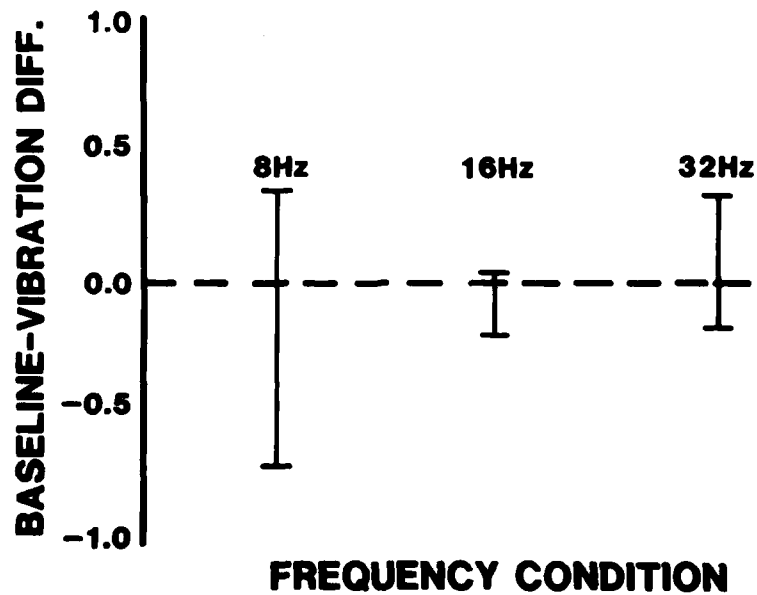


Figure 5: Ranges of Vibration Baseline Differences Over Three Frequencies.

Figure 6 illustrates the complexity of the trial effects. As shown by the figure, the means could be viewed as a learning curve with a mid-trials let down decrement.

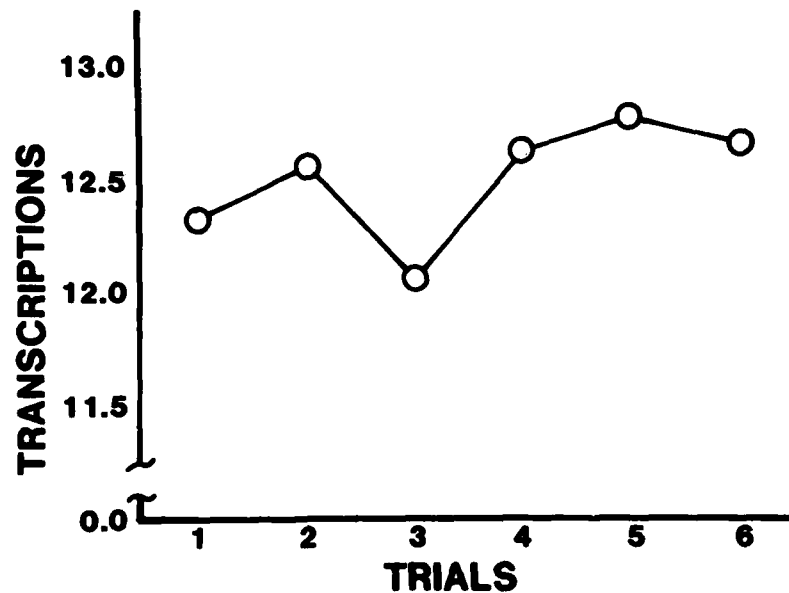


Figure 6: Auditory Response Average Transcriptions Over Trials.

Subjects' subjective estimates of decrement in hearing, thinking, and key punching were calculated. As can be seen in Figure 7, hearing was estimated to have the greatest remaining capacity, followed by thinking, then punching. Significantly, subjects rated keypunching 1.35 times more difficult under vibration, than under no vibration.

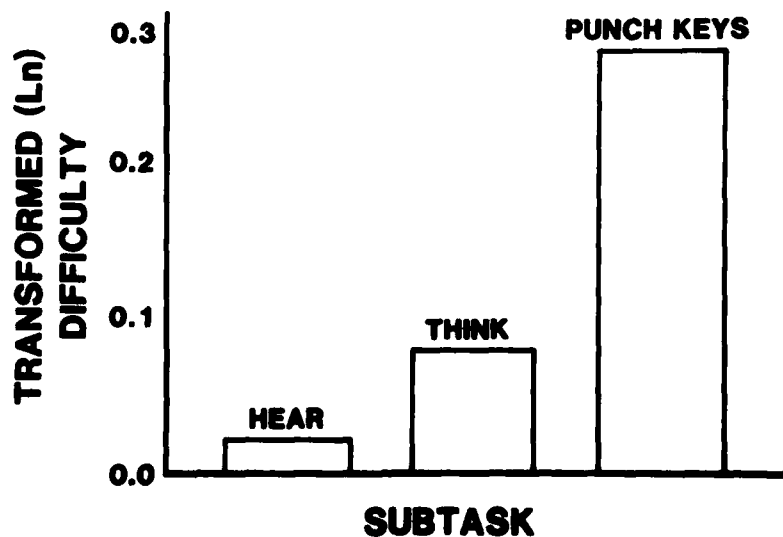


Figure 7: Relative (Vibration/No Vibration) Difficulties of Three Auditory Keypad Subtasks.

The moderately significant subjects-within-conditions by frequency interaction paired with subjective measures taken during experimentation, pointed to a deficit in the keypad output system. It was concluded that the system was not satisfactory for future experimentation and recommended that a modified input system be developed. It was noted that purely cognitive effects of vibration have not been identified in the body of previous research.

#### Future Research

Research at NBDL is currently aimed at investigating the etiology of human performance decrements under vibration. A literature review has been initiated with special focus on the questions of mechanical versus cognitive effects. It is noteworthy that, so far, no instance of vibration decrement has been found that clearly can be attributed to cognitive effects, but the issue is still open. Supplementing this effort, an experimental program is underway. A modified input system has been designed, and preliminary evaluation has been completed. The modified system employs a method of securing the hand to the keypad using a glove and velcro contact. In addition, a table top independent of vibration has also been provided to give arm and shoulder stability. The objective is to eliminate input/output related error which conceals any true cognitive decrements due to vibration. Preliminary analysis suggests the current version of the auditory-input/keypad output task is virtually free of mechanical interference. Present plans are to utilize the system, which appears to be free of mechanical artifacts, to test for "purely" cognitive effects by simply modifying the task to include information processing. Running serial memory, for example, can be tested by requiring responses for digits presented several steps previously. A wide variety of cognitive processing tasks can be tested for sensitivity to vibration. The outcomes of the etiology review and experimentation should provide the focus of our future efforts.

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3 Papers which are listed in the Appendices are not repeated in the Reference Section.

APPENDIX A<sup>4</sup>SELECTED BIBLIOGRAPHY OF  
PERFORMANCE EVALUATION TESTS FOR ENVIRONMENTAL RESEARCH PUBLICATIONS

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